



Effects of salicylic acid, putrescine and moringa leaf extract application on storability, quality attributes and bioactive compounds of plum cv. 'Golden Japan'

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Background: Plum fruits constitute a good source of natural antioxidant substances. Particularly, plums contain large amounts of phenolic compounds and flavonoids that have natural antioxidant activity which is useful to human health. The study aimed to evaluate the effects of foliar sprays with salicylic acid (SA), putrescine (PUT) and moringa leaf extract (MLE) on the fruit quality attributes and bioactive compounds of 'Golden Japan' plums under cold storage conditions. Plum trees were sprayed twice; at fruit set stage and one month later during seasons 2018 and 2019 by combinations from SA (3 and 4 mmol/L), PUT (3 and 4 mmol/L) and MLE (5 and 10%), as well as distilled water (control). Fruits were harvested at maturity stage and stored at 0°C with relative humidity 85-90% for eight weeks.

Results: With advance storage period, fruit weight loss, total soluble solids (TSS), total carotenoids content (TCC) and total phenolics content (TPC) increased significantly while the fruit firmness, lightness (L*), hue angle (h°) of colour, titratable acidity (TA), total flavonoids content (TFC) and antioxidant activity (AA) decreased significantly ($P < 0.05$). Statistically significant differences were observed between different treatments in maintenance on all measured parameters when compared to control. At the same time, a combined SA at 3mmol/ L, PUT at 4 3mmol/ L and MLE at 10% treatment was found to be more effective than other treatments in decreasing the weight loss, softening and maintaining titratable acidity, total carotenoids, total phenolics, total flavonoids and antioxidant activity in plum fruits during storage at 0 °C.

Conclusion: It was concluded that preharvest treatment of plum fruits with salicylic acid, putrescine and moringa leaf extract was effective in delaying the ripening processes and can be used commercially to extend the storage life of postharvest plum fruits with acceptable fruit quality.

1. Introduction

Golden Japan plum cultivar (*Prunus salicina* Lindl.) is member of the Rosaceae family belonging to the Japanese species, which mainly consumed fresh. Jap-

anese plums have short postharvest life depending upon the cultivar and supply-chain conditions. The low-temperature storage at 0 °C is recommended for



extending the storage and shelf life of plums facilitating prolonged marketability period and long-distance transport (Singh and Singh, 2012). Excessive softening of fruit flesh is the basic factor shortening storage time, shelf life and decreasing the market value of the fruit. Preservation of fruit firmness provides the preservation of taste, flavour and fruit texture and consequently increases plum consumption (Crisosto et al., 2004). There are several methods to prolong storage life and to preserve the quality of horticultural crops. One of them is to apply plant growth regulators and polyamines before and after harvest (Kucuker and Ozturk 2014; Davarynejad et al., (2015).

Salicylic Acid (SA) is an endogenous plant growth regulator and it has been found to generate a wide range of metabolic and physiological responses in plants thereby affecting their growth and development. SA as a natural and safe phenolic compound exhibits a high potential in controlling postharvest losses of horticultural crops (Asghari and Aghdam 2010). Preharvest application of SA has been shown to be effective in enhancing resistance to pathogens, controlling postharvest decay and a remarkably maintaining the fruit quality during postharvest storage life of peach (Wang et al., 2006), sweet cherry (Xu and Tian 2008), persimmon fruits (Khademi et al., 2012), plum (Davarynejad et al., 2015), nectarine (Bal 2016) and apple fruits (Aly et al., 2019).

Putrescine (PUT) is a polyamine, low molecular weight found in living organisms (Galston and Sawhney 1990). Many studies have shown that exogenously applied PUT affect fruit quality through some change in fruit firmness, weight loss, ethylene evolution, total soluble solids, titratable acids, reduced fruit deterioration and increased shelf life in many fruits (Martinez-Romero et al., 2002; Khan et al., 2008; Ba l.2012; Abbasi et al., 2019).

Moringa leaf extract (MLE) is a supplement or alternative to inorganic leaf fertilizer (Phiri 2010). It contains important minerals, proteins, vitamins, β carotene, amino acids and various phenolics that provide a rich and rare combination of zeatin with several flavonoid pigments (Siddhuraju and Becker 2003). So it is a good source of natural antioxidants (Jacob and Shenbagaraman 2011). Several studies pointed out that spraying moringa leaf extract increased the yield and percentage of marketable fruit and decreased the per-

centage of unmarketable fruits (Sheren and El-Amary 2015; Nasira et al., 2016; Thananaa et al., 2017).

This study aimed to evaluate the effects of preharvest treatment with salicylic acid, putrescine and moringa leaf extract on weight loss, fruit firmness, colour, total soluble solids, titratable acidity, total carotenoids, total flavonoid, total phenolic and total antioxidant activity of Japanese plums cv. Golden Japan under storage conditions at 0°C.

2. Materials and methods

This study was carried out during two successive seasons 2018 and 2019 on Ten-year-old plum (*Prunus salicina* Lindl.) cv. Golden Japan budded on Myrobalan plum (*Prunus cerasifera*) rootstock and planted at 5× 5 m in loamy clay soil under surface irrigation systems in a private orchard in Ashmoun, Monofia Governorate, Egypt. Fifteen trees uniform in vigour, trained on open vase a training system were chosen randomly as three trees/ treatment. Selected trees were sprayed twice; at fruit set stage (15th and 12th March in both seasons, respectively) and one month later during the years 2018 and 2019.

The treatments applied were:

T1: Control (Water only)

T2: 3 mmol/L SA+ 3 mmol/L PUT + 5 % MLE

T3: 3 mmol/L SA+ 4 mmol/L PUT +10% MLE

T4: 4 mmol/L SA+ 3 mmol/L PUT + 5% MLE

T5: 4 mmol/L SA+ 4 mmol/L PUT + 10%MLE

Preparation of moringa leaf extract

The aqueous extract of moringa leaves was prepared according to the method described by Thananaa et al., (2017), soaking 100 g of air-dried moringa leaves in 1 litre of water for 24 hours, then filtered and diluted with water to 5%, 10% and sprayed directly on the trees thoroughly sprayed till runoff (about 4-5 litre/tree). Tween-20 at 0.01% was added as a surfactant.

Undamaged mature plum fruits, free from apparent pathogen infection, uniform in shape, weight and colour were picked separately from each treated group. Fruits were harvested in the first week of June during each study season. Samples (approximately 90 fruits) were collected from three trees per each treatment,



then fruits were transported to the laboratory and packed in perforated carton boxes. Each treatment was packed in six boxes, and classified into three groups. The first group contained fruits for periodical determination of physical and chemical properties, the second group contained fruits for determination of weight loss and the third group contained fruits for determination of decay per cent. Fruits were stored at 0°C with relative humidity (RH) 85-90% for eight weeks. Assay of the stored fruits were determined at 2 weeks intervals, as follows:

Physical properties

Weight loss percentage: The difference between the initial weight of the fruits at the beginning of storage and that recorded at the date of sampling was translated as weight loss percentage and calculated as follows:

$$\text{Weight loss \%} = \frac{\text{Weight at the date of sampling (g)}}{\text{Initial weight of the fruits (g)}} \times 100$$

Fruit firmness (Lb/in²): fruit firmness was determined as Lb/in² by using fruit pressure tester mod. FT 327 (3-27 Lbs).

Fruit color: Lightness (L*) and hue angle (h°) were estimated using Minolta Colorimeter (Minolta Co. Ltd., Osaka, Japan) as described by Mc Gire (1992).

Decay percentage: The percentage of disordered fruits included all of the spoiled fruits from rots, fungus, bacterial and pathogens, results were assessed and the defects were calculated as follows:

$$\text{Decay \%} = \frac{\text{No. of fruit decay}}{\text{No. of fruit at the beginning of storage}} \times 100$$

Chemical properties

Total soluble solids (TSS): Percentage of TSS was determined in plum fruit juice using Digital refractometer PR32 (Atago Paleta ATago.CO .LTD. Japan).

Titrateable acidity (TA): Percentage of TA was determined by titrating the juice against 0.1 N sodium hydroxide using phenolphthalein indicator and expressed as a percentage of malic acid according to AOAC (2000).

Total carotenoids content (TCC): Carotenoids content of fruits was extracted by direct dipping of 10 gm of fruit pulp into a solution containing 40 ml acetone, 60 ml hexane and 0.1 g Mg Co₃ and blended for 5 minutes. It was determined by colourimeter according to AOAC (2000). The TCC was expressed as mg /100 g extract.

Total flavonoids content (TFC): The TFC was measured by a colourimetric assay developed by Zhishen and others (1999). The absorbance of the mixture was determined at 510 nm versus a prepared water blank. Quercetin was used as the standard for the calibration curve. The TFC was expressed as mg quercetin equivalents (QE) /100 g extract.

Total phenolics content (TPC): TPC in the juice was determined using the Folin-Ciocalteu method (Meighani et al., 2014). Total phenolic content was expressed as mg gallic acid equivalent in 100 mL of juice (mg gallic acid /100 mL juice).

Antioxidant activity (AA): AA was assessed according to the method of Ismail and others (2009). In brief, 1 g of plum tissue was extracted with 10 ml methanol (85%). One ml of this extract was mixed with 2 ml of 0.15 mM DPPH (1,1-diphenyl-2-picrylhydrazyl) in methanol. The mixtures were shaken vigorously and left to stand for 30 min (under dark conditions). The control was prepared by adding 2ml of DPPH to 1ml methanol. Absorbance of the resulting solution was measured at 517 nm by a Cecil 2010 UV-visible spectrophotometer. The antioxidant activity is expressed in the form of the percentage of free radical scavenging.

Statistical analysis

A randomized complete block design was used for analysis of variance for comparison between the control and the others. All data were subjected to statistical analysis according to the procedures reported by Snedecor and Cochran (1990) and means were compared by Duncan's multiple range tests at the 5 % level of probability.

3. Results

Weight loss percentage

Figure 1 cleared that a gradual increase in weight loss



was shown towards the end of the storage period (8 weeks). Significant differences between regardless of all treatments. The lowest weight loss percentage (12.63 and 12.25%) was recorded by the mixture application of 3SA+ 4PUT+10MLE in two seasons, respectively. On the other hand, control fruits exhibited the highest weight loss value (16.97 and 14.81%) in the first and

second seasons, respectively.

Fruit firmness

Data obtained regarding fruit firmness, presented in Figure 2 shows that firmness decreased with the progress of storage periods in both seasons. There

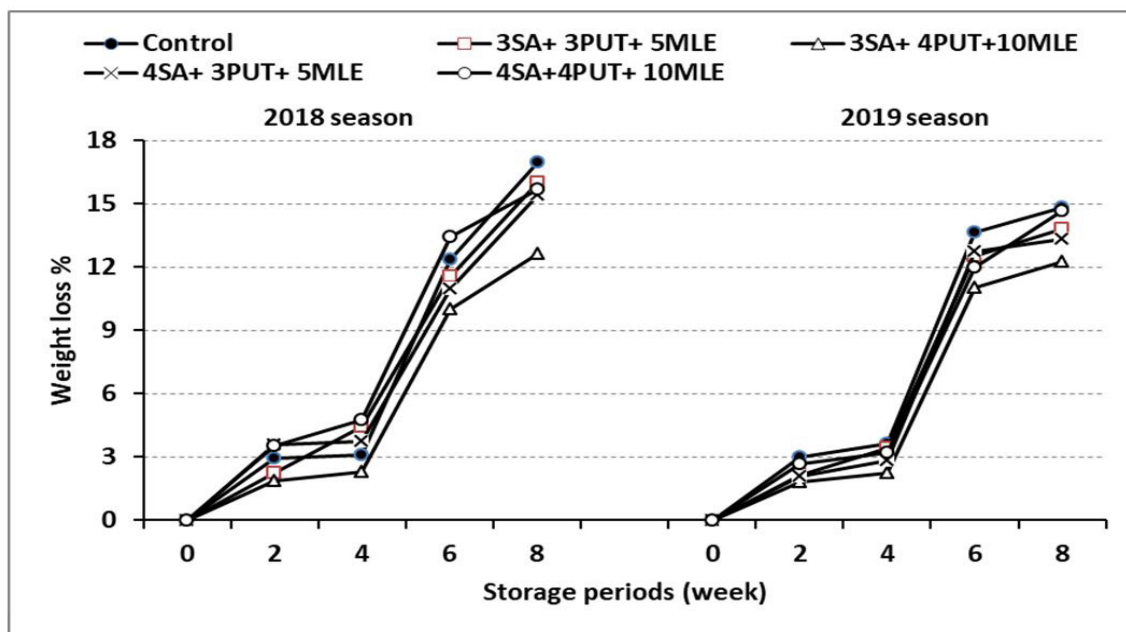


Figure 1. Effect of some pre-harvest treatments on weight loss % of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%

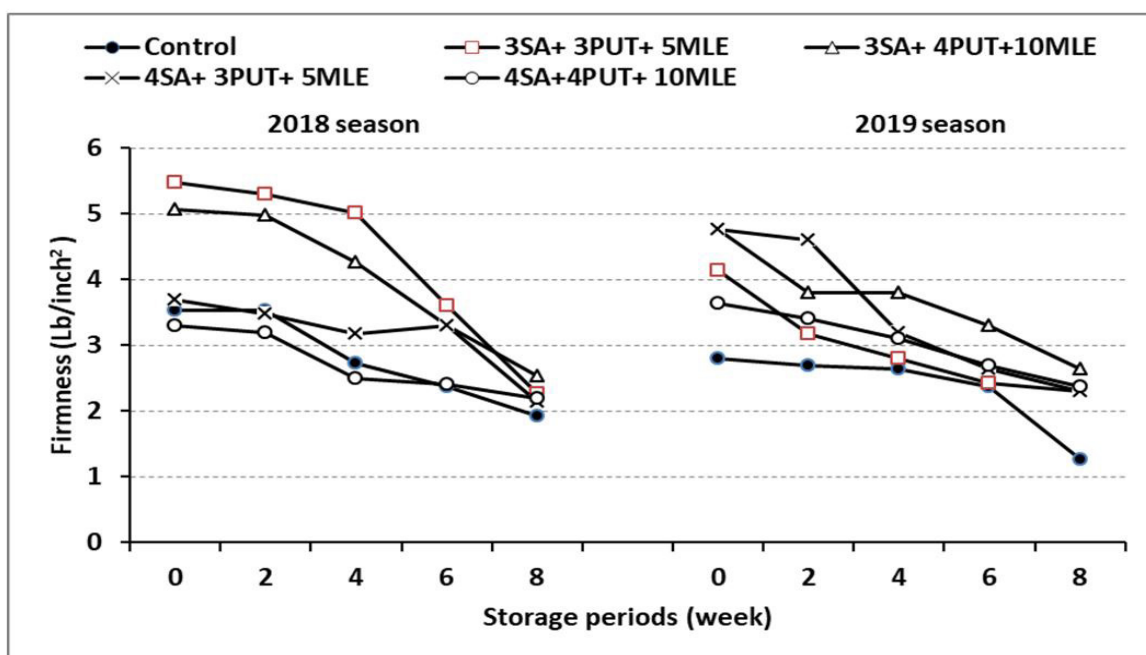


Figure 2. Effect of some pre-harvest treatments on fruit firmness of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%



were significant differences among all treatments compared with control fruits in both seasons. At the end of storage, fruits that were treated with 3SA+4PUT+10MLE had significantly higher fruit firmness. On the contrary, control fruit treatment exhibited the lowest values of fruit firmness in the two seasons.

Fruit colour

Lightness (L*)

Data are shown in Table 1 indicate that, lightness (L*) significantly decreased with prolonging of storage period during the two seasons. At the end of the storage period, fruits treated by 4SA+ 3PUT+ 5MLE and 3SA+ 3PUT+ 5MLE recorded the highest significant difference of L* in the first and second

seasons (48.85 and 46.98), respectively. Control fruits treatment exhibited the lowest values of L* (43.39 and 44.83) in the two seasons, respectively.

Hue angle (h° value)

Hue angle (h°) was decreased (increase density of yellow colour) with the advance in cold storage period (Table 2). Significant differences between all treatments were observed in the 2018 and 2019 seasons. At the end of the storage period, the lowest value of h° (high density of yellow colour) was recorded by 3SA+ 4PUT+10MLE in the two seasons. On the contrary, the highest values were recorded with control and 3SA+ 3PUT+ 5MLE treatments in first and second seasons, respectively.

Table 1. Effect of some pre-harvest treatments on L of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%

Treatments	Storage period per week					Storage period per week				
	2018					2019				
	0	2	4	6	8	0	2	4	6	8
Control	62.47C	61.36A	58.55A	58.55A	43.39D	59.75D	59.61C	58.11B	56.18A	44.83C
3SA+ 3PUT+ 5MLE	61.24C	55.62B	52.88B	48.72C	46.27C	62.09C	55.96D	55.22C	47.12D	46.98A
3SA+ 4PUT+10MLE	65.34B	56.85B	50.71C	49.02C	47.86B	63.51B	63.14A	53.67D	48.48C	46.86AB
4SA+ 3PUT+ 5MLE	67.78A	59.55A	58.77A	52.66B	48.85A	57.73E	60.86B	59.46A	49.20C	46.87AB
4SA+4PUT+ 10MLE	60.28C	59.66A	59.41A	49.76C	47.02BC	67.87A	61.15B	60.06A	52.42B	46.22B

Means within a column, following with the same letters are not significantly different according to Duncan multiple ranges test at the probability of 0.05 levels.

Table 2. Effect of some pre-harvest treatments on h° of plum fruit 'Golden Japan' during storage at 0 °C and RH 85-90%

Treatments	Storage period per week					Storage period per week				
	2018					2019				
	0	2	4	6	8	0	2	4	6	8
Control	104.5B	103.8A	104.0A	101.8A	100.1A	103.5AB	101.8B	101.7B	101.1A	95.93C
3SA+ 3PUT+ 5MLE	104.2B	103.7A	100.4BC	97.63B	97.19C	103.9A	103.6A	102.7A	99.62B	98.31A
3SA+ 4PUT+10MLE	102.2D	100.6C	99.34C	97.51B	94.46D	103.1BC	102.0B	100.1C	98.81C	95.35C
4SA+ 3PUT+ 5MLE	103.4C	101.7B	101.1B	100.9A	98.29B	103.8A	101.9B	101.6B	99.42BC	96.88B
4SA+4PUT+ 10MLE	105.6A	102.9A	101.1B	97.81B	97.20C	102.6C	99.31C	97.16D	96.66D	96.30BC

Means within a column, following with the same letters are not significantly different according to Duncan multiple ranges test at the probability of 0.05 levels.



Decay percentage

It is clear from the data in Figure 3 that all treatments significantly decreased decay percentage than the control fruits. However, all the used treatments did not give any decay fruits before 8 weeks of storage.

After 8 weeks of storage, data showed that fruits treated by 3SA+ 4PUT+10MLE recorded the lowest significant difference of decay percentage (4.5 and 3%) in the two seasons, respectively. On the contrary, control fruit treatment exhibited the highest values of decay percentage (50 and 45%) in the first and second seasons, respectively.

Total soluble solids (TSS)

Results in Table 3 display that Total Soluble Solids (TSS) content of fruits was gradually increased with the advance in cold storage up to 6 weeks and decreased after that. The statistical analysis indicated that there was a significant difference between the treatments during the storage periods in the two seasons of the study. After 8 weeks of storage, the highest values of TSS% were noticed by fruits treated by 4SA+ 3PUT+ 5MLE in the two seasons. On the contrary, 3SA+ 3PUT+ 5MLE fruits treatment exhibited the lowest percentage of TSS% in both seasons.

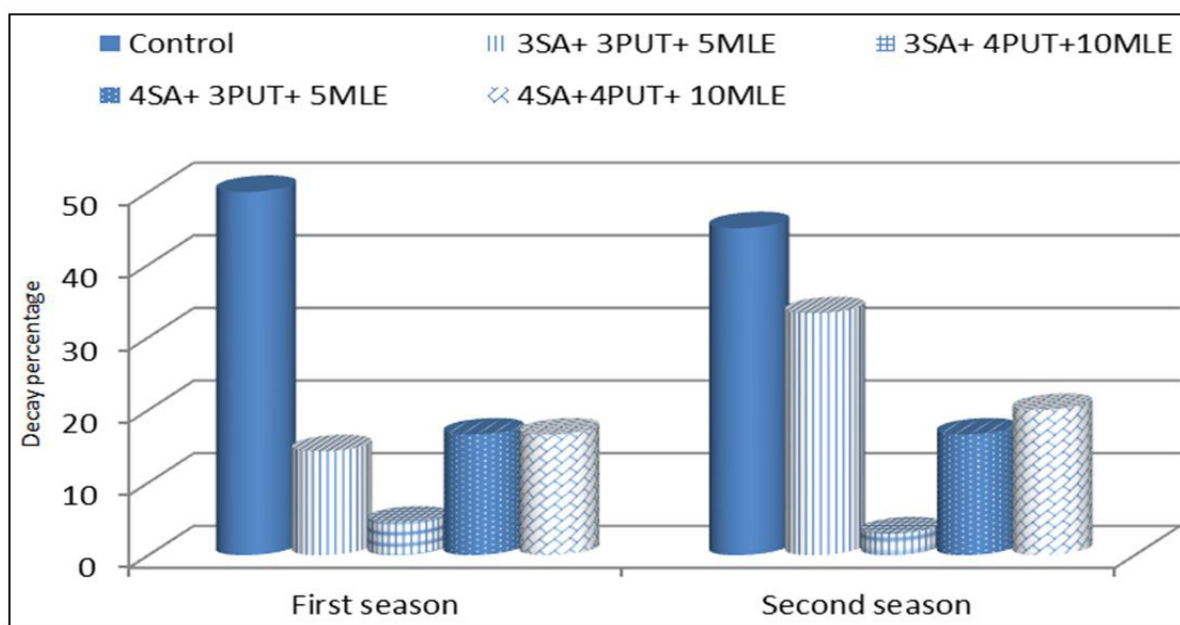


Figure 3. Effect of some pre-harvest treatments on decay percentage after 8 weeks of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%

Table 3. Effect of some pre-harvest treatments on TSS % of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%

Treatments	Storage period per week					Storage period per week				
	2018					2019				
	0	2	4	6	8	0	2	4	6	8
Control	10.20B	10.20B	12.20B	12.50B	13.27C	10.40B	10.33B	10.27C	12.50A	13.03B
3SA+ 3PUT+ 5MLE	13.07A	13.47A	13.54A	10.27C	10.27D	11.04A	12.07A	10.23C	10.30C	13.46AB
3SA+ 4PUT+10MLE	10.27B	10.27B	12.17B	13.30A	14.20A	10.27B	10.27B	11.13B	12.67A	13.51A
4SA+ 3PUT+ 5MLE	13.10A	10.27B	10.27D	13.50A	13.50B	10.23B	10.27B	12.73A	12.93A	13.17AB
4SA+4PUT+ 10MLE	10.23B	10.33B	11.23C	12.53B	13.50B	10.30B	10.30B	10.40C	11.27B	13.07B

Means within a column, following with the same letters are not significantly different according to Duncan multiple ranges test at the probability of 0.05 levels.



Titrateable acidity (TA)

TA of plum fruits decreased in all treatments with the progress of a cold storage period during both seasons of the study (Table 4). No significant difference between all treatments in most cases. Fruits treated by 3SA+ 4PUT+10MLE recorded the lowest TA% (0.061 & 0.063%) in the first and second seasons, respectively. Meanwhile, the untreated fruit recorded the highest TA% (0.066 & 0.071%) in the two seasons, respectively.

Total carotenoids content (TCC)

As clear in Figure 4, total carotenoids content was increased with the advance in cold storage periods. Significant effects by treatments were noticed in the 2018 and 2019 seasons. At the end of the storage period, the highest values were recorded with 3SA+ 4PUT+10MLE treatment in both seasons. While the lowest value of total carotenoids content was recorded by control in the two seasons.

Table 4. Effect of some pre-harvest treatments on titrateable acidity (%) of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%

Treatments	Storage period per week					Storage period per week				
	2018					2019				
	0	2	4	6	8	0	2	4	6	8
Control	0.120A	0.070B	0.070A	0.067A	0.066A	0.101AB	0.094A	0.078A	0.074A	0.071A
3SA+ 3PUT+ 5MLE	0.101BC	0.094A	0.078A	0.074A	0.063A	0.112A	0.071B	0.067A	0.065A	0.064A
3SA+ 4PUT+10MLE	0.087C	0.083AB	0.069A	0.065A	0.061A	0.080C	0.078AB	0.074A	0.067A	0.063A
4SA+ 3PUT+ 5MLE	0.110AB	0.078AB	0.067A	0.065A	0.064A	0.094BC	0.087AB	0.069A	0.067A	0.067A
4SA+4PUT+ 10MLE	0.098BC	0.083AB	0.071A	0.071A	0.065A	0.101AB	0.076B	0.069A	0.067A	0.067A

Means within a column, following with the same letters are not significantly different according to Duncan multiple ranges test at the probability of 0.05 levels.

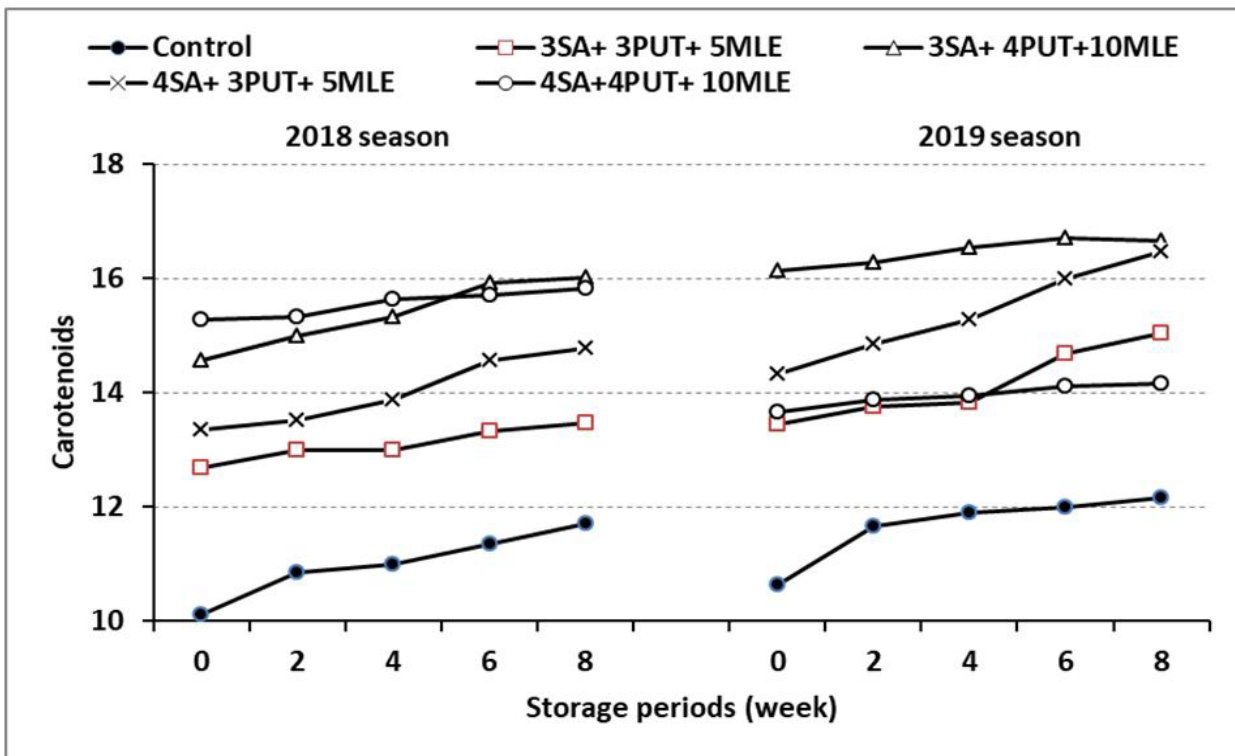


Figure 4. Effect of some pre-harvest treatments on total carotenoids content of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%



Total phenolics content (TPC)

As shown in Figure 5, total phenolics content increased significantly by the conducted treatments and the storage periods. After 8 weeks of storage, the highest value of total phenolic content (78.83 and 78.86) was recorded by 3SA+ 4PUT+10MLE in both seasons, respectively. On the other hand, 4SA+4PUT+ 10MLE treatment exhibited the least values (70.81 and 72.85) in the first and second seasons, respectively.

Total flavonoids content (TFC)

Data shown in Figure 6 indicate that total flavonoids content decreased gradually and significantly with extended storage periods during the two seasons. At the end of storage, the highest value was obtained by fruits treated with 3SA+ 4PUT+10MLE in the first season and 4SA+ 3PUT+ 5MLE in the second season without a significant difference between them.

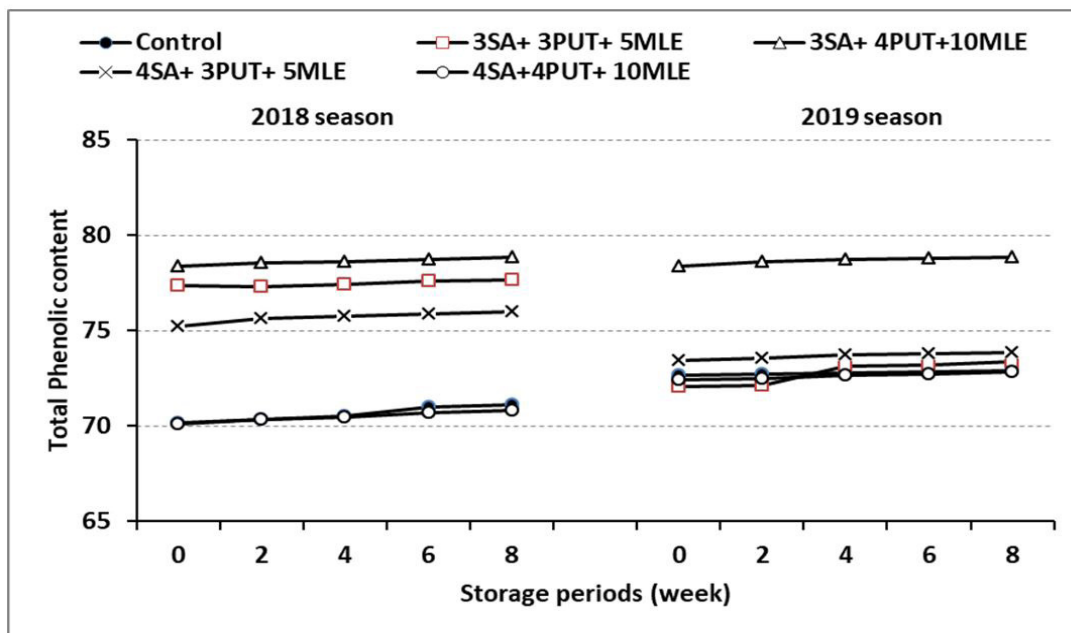


Figure 5. Effect of some pre-harvest treatments on total phenolic content of plum fruit 'Golden Japan' during storage at 0 °C and RH 85-90%

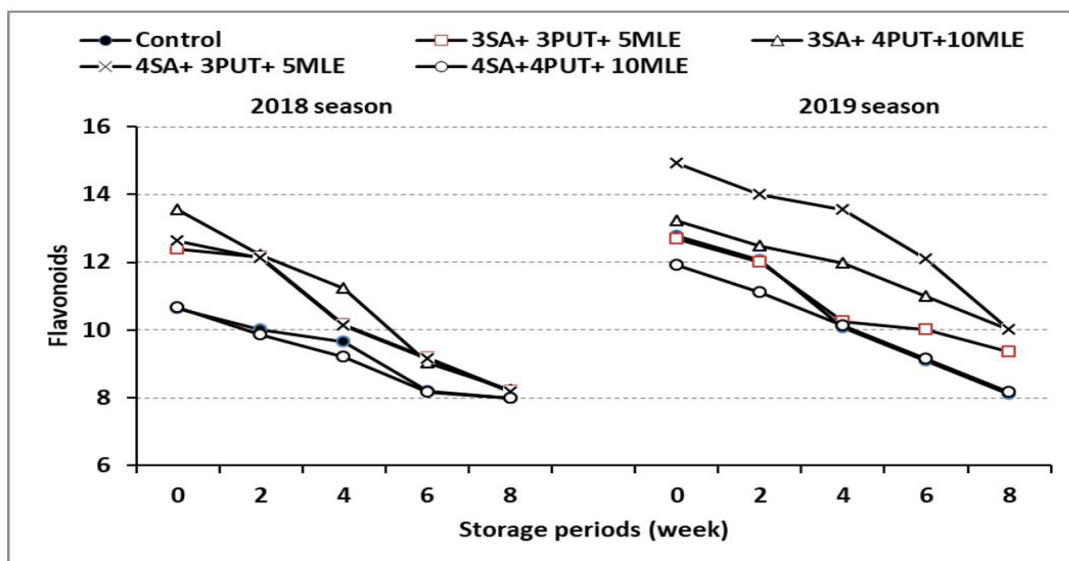


Figure 6. Effect of some pre-harvest treatments on total flavonoids of plum fruit 'Golden Japan' during storage at 0 °C and RH 85-90%



Antioxidant activity (AA)

Results in Table 5 show that all studied treatments increased antioxidant activity more than the control fruits. However, antioxidant activity decreased with the advance in cold storage period. After 8 weeks of storage, the highest significant difference of antioxidant activity was recorded by 4SA+ 3PUT+ 5MLE in both seasons. On the other hand, control treatment exhibited the least significant antioxidant activity in the two seasons.

4. Discussion

In the present study, foliar application of SA, PUT and MLE on plum 'Golden Japan' trees resulted in a significantly slower rate of physiological fruit weight loss during storage at 0°C, and these results were consistent with those previously reported by Serrano et al., (2003), Ghasemnezhad et al. (2010), Davarynejad et al., (2015) who found that the exogenous application of putrescine caused significantly less fruit weight loss during storage. It was previously showed that the weight loss of apple fruit significantly decreases in salicylic acid treatment in comparison to control treatment during storage (Díaz-Mula et al., 2009).

The weight loss of fruit throughout the storage period could be due to the water exchange between the internal and external atmosphere, and the transpiration rate is accelerated by the cellular breakdown (Woods 1990). The obtained results detected that putrescine treatment decreased weight losses during storage. This effect might be due to a modification in a delay of the removal of epicuticular waxes which play an impor-

tant role in water exchange through the skin. Zheng and Zhang (2004) reported that salicylic acid caused a reduction in the rate of respiration and weight loss of fruit by closing stoma. Moreover, Abbasi et al., (2019) reported a negative correlation between concentrations of salicylic acid, putrescine and weight loss, this may be due to its anti-senescence properties (Foidle et al., 2001); Nasira et al., 2016). The MLE may have maintained the membrane stability or integrity of the epicuticular wax of plum fruit, thereby reducing the rate of moisture loss from the fruit during cold storage.

Fruit softening is another important factor responsible for limiting the storage life of horticultural crops (Brummell and Harpster 2003). It is associated with deleterious changes in the metabolism of cell wall carbohydrates as well as the structural components of the cell wall (Labavitch 2003). These changes are triggered by the activities of hydrolytic enzymes (Payasi et al., 2009). In this study, the maintenance of higher flesh firmness of 'Golden Japan' plum in response to salicylic acid and putrescine and moringa leaf extract application may be attributed to the reduced activities of the fruit-softening enzymes. These results are in agreement with Aghdam et al., (2009) in kiwifruit; Valero et al., (2011) in sweet cherry; Abbasi et al., (2019) in peach who found that treatment with exogenous polyamines has been reported to maintain fruit firmness during storage. Also, Serrano et al., (2003) and Davarynejad et al., (2015) reported that the treated plum fruits with salicylic acid and putrescine had the highest level of fruit firmness during storage.

Most fruits lose firmness and soften with an accelera-

Table 5. Effect of some pre-harvest treatments on Anti-oxidant of plum fruit 'Golden Japan' during storage at 0°C and RH 85-90%

Treatments	Storage period per week					Storage period per week				
	2018					2019				
	0	2	4	6	8	0	2	4	6	8
Control	57.58D	57.33C	53.78D	50.45E	50.11E	60.17E	60.00E	59.26E	55.17E	52.08E
3SA+ 3PUT+ 5MLE	57.63C	57.19D	55.37C	54.82C	52.25C	67.19C	66.34C	64.67C	63.88A	61.00B
3SA+ 4PUT+10MLE	69.17A	65.18B	64.62A	60.09B	60.00B	68.11B	67.22B	65.55B	63.71B	60.16C
4SA+ 3PUT+ 5MLE	67.78B	65.73A	62.61B	62.08A	61.94A	68.54A	68.01A	66.35A	63.46C	62.15A
4SA+4PUT+ 10MLE	56.18E	55.09E	53.43E	52.44D	50.27D	66.09D	65.87D	63.81D	61.94D	59.00D

Means within a column, following with the same letters are not significantly different according to Duncan multiple ranges test at the probability of 0.05 levels.



tion of the ripening process, exhibiting a loss of quality during the storage period. The polyamines influence on firmness augmentation can be attributed to their capacity cross-link to pectic substances in the cell wall, resulting in rigidification that is detectable immediately after treatment (Abbott et al., 1989) and also as inhibition of the action of wall-degrading enzymes, such as pectinesterase, pectin methylesterase and polygalacturonase, which reduces fruit softening during storage (Valero et al., 2002). Kazemi et al., (2011) reported that the effect of salicylic acid on the reduction of fruit softening can be attributed to ACO (1-aminocyclopropane-1-carboxylic acid oxidase) inhibitory activity, and therefore on ACC (1-aminocyclopropane-1-carboxylic acid) conversion to ethylene. Following this hypothesis, the exogenously applied putrescine and salicylic acid went to cell walls to maintain high levels of fruit firmness and these high levels of firmness lead to increased shelf life.

Fruit colour plays an important role in consumer attraction. Plum fruit colour is associated with the accumulation of carotenoids and anthocyanins. Both groups of pigments are more abundant in the peel but carotenoids are mainly responsible for the surface colour of 'Golden Japan' plums. The ripening phenomenon in fresh produce is meticulously associated with the degradation of photosynthetic pigments coupled with the concomitant increases in the levels of phenolic pigments. Similarly, storage regime substantially influences the exterior colour (Abbasi et al., 2019). The slower changes in the lightness (L^*) and hue angle (h°) on the surface of plum fruit after SA, PUT and MLE application may be ascribed to the delay in chlorophyll senescence with the reduced rate of fruit ripening.

These results are in harmony with those obtained by Martínez-Esplá et al., (2017) who reported that the application of salicylic acid has been a successful production practice to ensure optimum colour development on the fruit surface after long-term cold storage was evaluated in two plum cultivars "Black Splendor" and "Royal Rosa". Similar data were also reported by treatment with exogenous polyamines for apricot (Martínez-Romero et al., 2001) and mango (Malik and Singh 2005). Additionally, applying preharvest with moringa leaf extract increases the pigment contents in fruits due to its mineral richness, which enhance the activity of enzymes, hence the appearance of coloured

pigments Thanaa and others (2017), and may this lead to high levels of fruit colour maintenance during ripening, either on trees or during storage.

Along with storage, TSS increased in plums from control and treated trees. The increase in total soluble solids content during storage was probably due to the concentrated juice content as a result of dehydration and hydrolysis of polysaccharides.

The obtained results indicated that all treatments showed significant increases in the content of total soluble solids during the storage period. This effect of salicylic acid, putrescine and moringa leaf extract can be attributed to its roles in lowering the respiration rate and delaying the conversion of starch into simple sugars and other impacts, such as decreasing the weight loss and ethylene biosynthesis, hence delaying the ripening process Davarynejad and others (2015).

This result is in accordance with that of Baljit and Jawandha (2014) who summarized that putrescine 3 mmol L⁻¹ sprayed 10 days before harvesting of peach fruits registered high TSS% at the end of storage. Moreover, Aly et al., (2019) found that pre-harvest foliar application with putrescine and salicylic acid at (200, 400, 600 ppm) significantly increased total soluble solids content of "Anna" apple during cold storage. Additionally, Thanaa et al., (2017) reported that foliar application of moringa leaf extract at full bloom stage, fruit setting stage and two weeks after fruit setting stage significantly increased the soluble solids content of "Hollywood" plum.

The titratable acidity is an important factor in maintaining the quality of plum fruits, which is directly related to the organic acid content present in the fruit. Zokae-Khosroshahi et al., (2007) and Ishaq et al., (2009) reported that the decrease of titratable acidity content could be due to consumption of organic acids in fruits during respiration. In the present study, it seems that salicylic acid, putrescine and moringa leaf extract treatments did have a significant effect on respiration process which could result in reduction or delay of respiration and maintain titratable acidity content. This result was in agreement with the report by Davarynejad et al., (2015) as well as Thanaa et al., (2017).

Plums have been reported as a rich source of antioxi-



idant compounds with beneficial health effects such as carotenoids and phenolics as compared with other fruits of the Mediterranean, although important differences in their concentration are found depending on the cultivar (Igwe and Charlton 2016); Sahamishirazi et al., 2017). It is interesting to note that SA, PUT and MLE preharvest treatment led to increased levels of total carotenoids (TCC) and total phenolic content (TPC) in 'Golden Japan' plum cultivar compared to control, as well as these levels remained still at significantly higher concentration after 8 weeks of storage. No previous reports published are available regarding the effect of these treatments either applied as a post or preharvest treatments on total carotenoid content, with the exception of one paper previously published. It showed that SA preharvest treatment of "Black Splendor" and "Royal Rosa" plum led to increasing total carotenoid content and maintenance during 50 days of storage compared to control fruits (Martínez-Esplá et al., 2017).

Concerning their effect on phenolic content, our results are in harmony with those obtained in plums (Martínez-Esplá et al., 2017), in sweet cherry (Giménez et al., 2016) and apricot (Wang et al., 2015). SA post-harvest treatment increased levels of total phenolics and these levels were maintained during cold storage. These enhancements may be attributed to an increase of phenylalanine ammonia lyase activity, which is the main enzyme involved in the biosynthetic phenolic pathway (Martínez-Esplá et al., 2017). On the other hand, Davarynejad et al., (2015) found that applying 4 mmol/L putrescine and 4 mmol/L salicylic acid treatments on 'Santa Rosa' plum significantly decreased the content of total phenolics during storage at 4°C.

In this study, total flavonoids content decreased gradually and significantly with extended storage periods. Similar results were found on peach fruits (Zhang et al., 2014) and on apples (Chaparzadeh and Yavari 2013). They reported that total flavonoids content decreased significantly towards the end of cold storage.

The decreases in flavonoid content were delayed by all treatments, especially application of 3mmol/LSA plus 4 mmol/L PUT plus 10% MLE, that produced the highest significant values than those found in the control which recorded the lowest flavonoid content. This could be mainly due to activating the metabolic pathway for the synthesis of flavonoid compounds with

SA, PUT and MLE preharvest treatment. These results are following the findings by Bal (2016) on nectarine fruits who reported that exogenous application of salicylic acid treatment at 0.5 mM significantly increased total flavonoid content by the 30th day of storage.

Reduction of antioxidant activity of 'Golden Japan' plum with the advance in cold storage period could be attributed to the reduction in TPC, TFC and other biochemical compounds.

This result agreed with Tsantili and others (2010) who reported that higher phenolic compound levels could change antioxidant activity and also showed a linear correlation between phenolic compounds and antioxidant activity. At the end of the storage period, the treatments of salicylic acid, putrescine and moringa leaf extract maintained antioxidant activity of the fruit significantly during storage. The highest significant different of antioxidant activity were recorded by 3mmol/L SA plus 4 mmol/L PUT plus 10% MLE), the lowest antioxidant activity was recorded in control fruits. This was probably due to it impacts in maintaining of TCC, TPC and TFC during storage. This is in agreement with Barman and Asrey, (2014); Davarynejad et al., (2015) and Bal (2016).

5. Conclusion

In conclusion, salicylic acid, putrescine and moringa leaf extract play a very effective role in controlling the fruit weight loss, decay, softening and other compositional changes such as titratable acidity, total soluble solids, total carotenoids, total phenolics, total flavonoids and antioxidant activity of plum fruits during cold storage. Especially SA at 3mmol/L, PUT at 4 mmol/L and MLE at 10% treatment delayed the ripening process more effectively and with minimum quality loss as compared to the control samples which had greater compositional changes with maximum quality loss. Thus, can be used commercially to extend the storage life of postharvest plum fruit and preserve fruits with acceptable quality attributes.

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Conflict of Interests

The authors hereby declare that there is no conflict of interests.

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